

REPORT No. 389

THE EFFECT OF SMALL ANGLES OF YAW AND PITCH ON THE CHARACTERISTICS OF AIRPLANE PROPELLERS

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SUMMARY

The subject tests were carried out in the 20-foot wind tunnel of the National Advisory Committee for Aeronautics to determine the effect on the characteristics of a propeller of inclining the propeller axis at small angles to the relative wind. Tests were made of a full-scale propeller and fuselage combination at four angles of yaw (0° , $+5^\circ$, $+10^\circ$, and $+15^\circ$), and of a model propeller, nacelle, and wing combination at five angles of pitch (-5° , 0° , $+5^\circ$, $+10^\circ$, and $+15^\circ$).

The results of the full-scale tests of a propeller and fuselage, without a wing, show that the effect on the propeller performance is small. Similar results are shown by the model test data except that where the propeller is directly in front of the wing there is an appreciable decrease in effective thrust and propulsive efficiency with increase of angle of pitch.

INTRODUCTION

In the prediction of airplane performance it is usual to assume that the line of thrust of the propeller is parallel to the flight path. This condition exists, of course, for only one particular angle of attack of the airplane. For any other angle of attack, especially when climbing or flying horizontally at low speeds, the thrust line is inclined at an angle to the line of flight. Previous model propeller tests have shown that the reduction in thrust is negligible for small angles of pitch. (Reference 1.) Such tests have been made, however, with the propeller alone, so the conditions do not correspond to those found in practice, where the propeller usually operates in front of a body such as a fuselage, nacelle, or wing.

The object of the tests described in this report was to determine the effect of inclining the thrust line at small angles to the relative wind on the characteristics of a propeller operating in front of a body. Two series of tests were made. The first series consisted of yaw tests of a full-scale propeller and fuselage. It would have been desirable to change the angle of pitch instead of that of yaw, but this was not possible with the torque dynamometer available, since it would not function properly except when in a level position. However, for the propeller and fuselage, without a wing, it is

obvious that changing the angle of yaw will cause a similar effect on the propeller performance to that caused by changing the angle of pitch. In the second series, a model propeller and nacelle were tested alone and in two positions relative to a wing, the combination being pitched at various angles. All the tests were made in the 20-foot tunnel of the National Advisory Committee for Aeronautics.

APPARATUS AND TESTS

The full-scale propeller and fuselage are shown mounted in the wind tunnel in Figure 1. The propeller was 9 feet in diameter and had two adjustable aluminum alloy blades. The curves for the blade form and pitch distribution are given in Figure 2. The propeller was driven by a 435-horsepower Curtiss D-12 engine mounted in an open-cockpit fuselage. A dynamometer for measuring the torque of the engine was also mounted in the fuselage. A description of this dynamometer, the thrust balance, and other wind-tunnel apparatus will be found in reference 3.

Tests were made at propeller pitch settings of 15.5° and 23.5° (at 0.75 radius) with the propeller axis yawed at 0° , 5° , 10° , and 15° . The method of conducting the tests was the same as that described in reference 2.

The method of supporting the model wing and nacelle in the wind tunnel is shown in Figure 3. The wing and nacelle pivoted about the top of the two wing supports, and the angle of pitch was changed by raising or lowering the end of the long sting extending in the rear of the wing. A 25-horsepower electric motor, for driving a 4-foot model propeller, was mounted in the nacelle. No means were available by which the torque of the motor could be measured directly; the motor torque was therefore calibrated, for a constant field excitation, using a Prony brake. Later the calibration was checked by means of a dynamometer. The wing was 15 feet 10 inches in span, 3 feet 2 inches in chord, and had a Clark Y airfoil section.

The 4-foot metal propeller used in the model tests was geometrically similar to the propeller used in the full-scale tests. It was first tested with the nacelle alone (fig. 4a), second with the nacelle above the

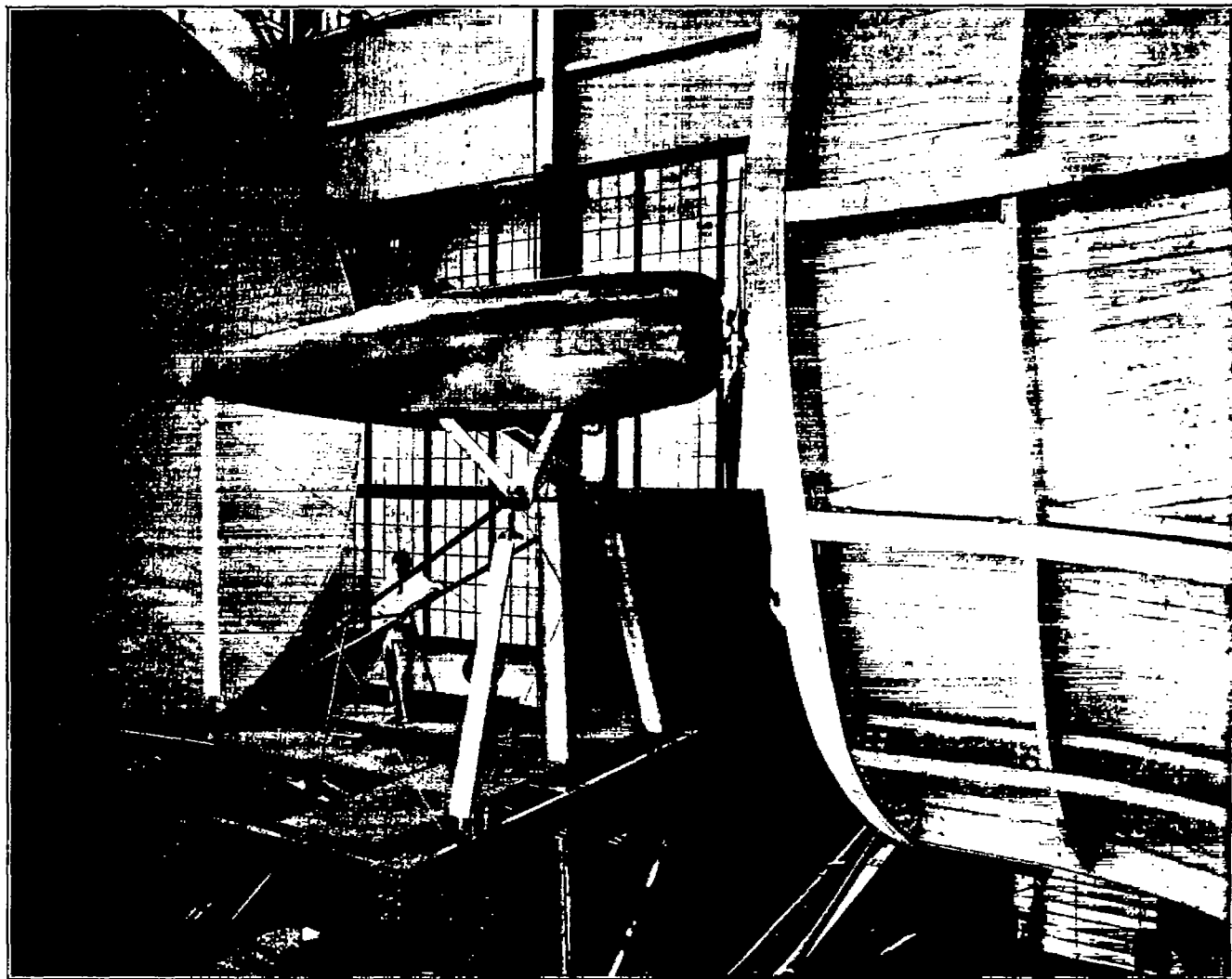


FIGURE 1.—Full-scale propeller and fuselage

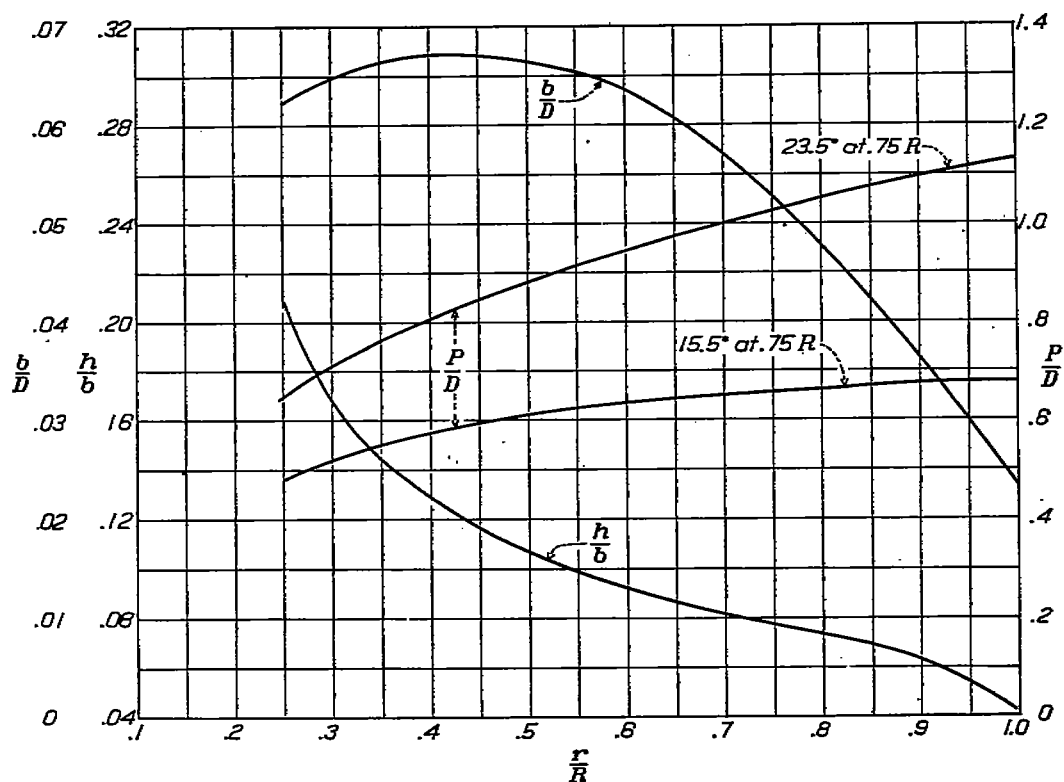


FIGURE 2.—Blade form curves. Propeller No. 4412. b =blade width; D =diameter of propeller; P =pitch; h =maximum blade thickness; R =radius of propeller; r =section radius

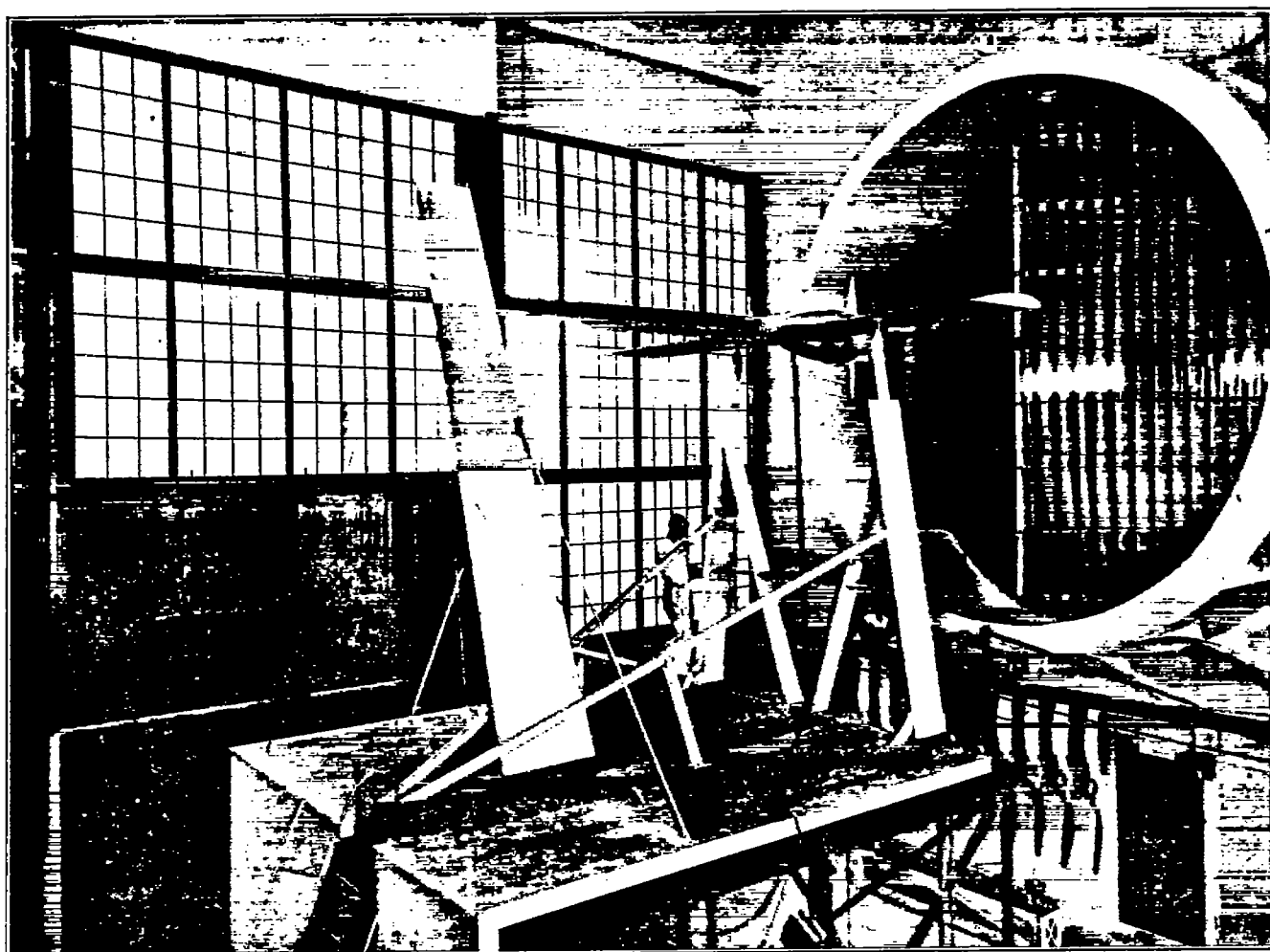
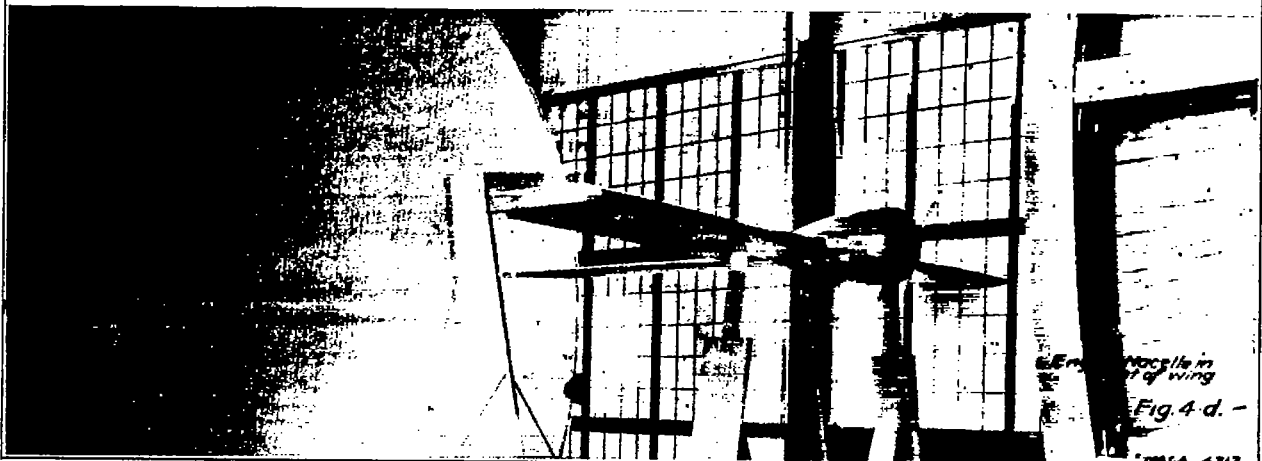
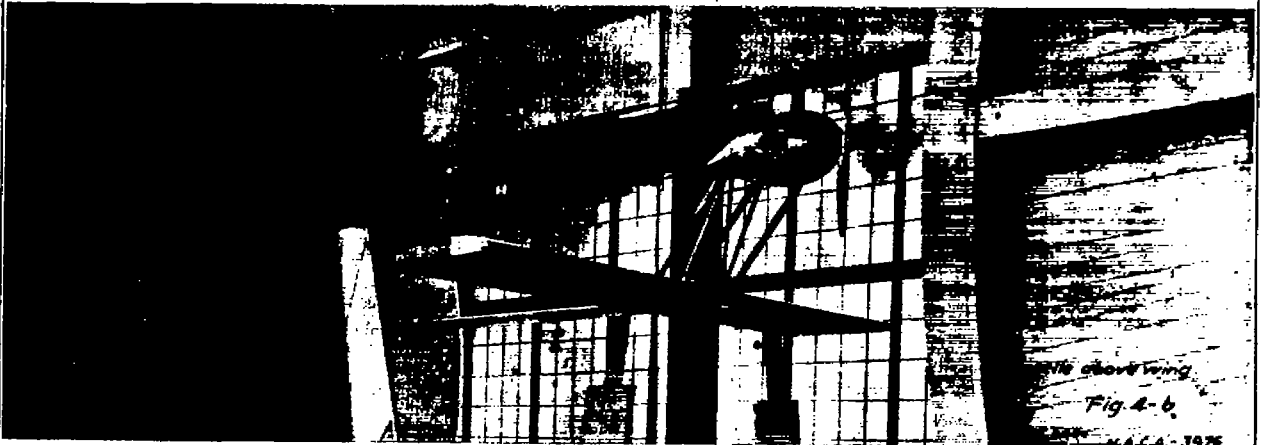


FIGURE 3.—Model engine, nacelle, and wing



wing (fig. 4b), and third in front of the wing (fig. 4c). Later dummy cylinders were fixed to the nacelle to simulate a Wright J-5 engine. The model engine was

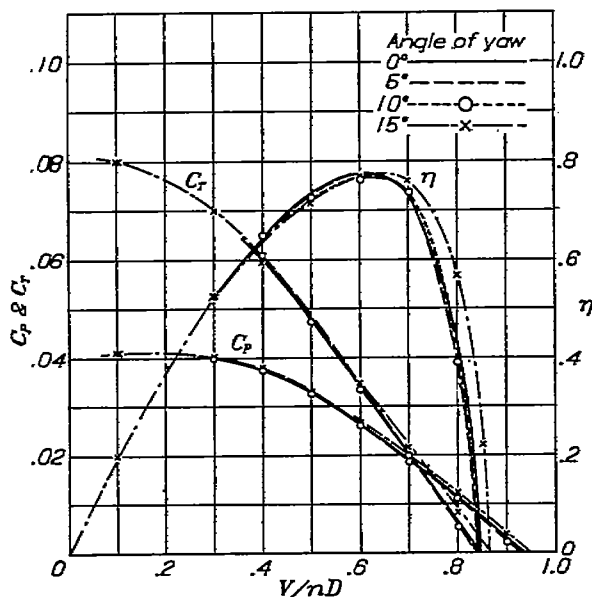


FIGURE 5.—Characteristics of propeller No. 4412, 15.5° at 0.75 R; diam. 9 ft.

provided with an N. A. C. A. cowling. This arrangement (fig. 4d) was tested in the same position relative to the wing as that shown in Figure 4c. All the arrangements were tested at four propeller blade settings (12°, 17°, 22°, and 27° at 0.75 radius) and with the thrust line at five angles of pitch (−5°, 0°,

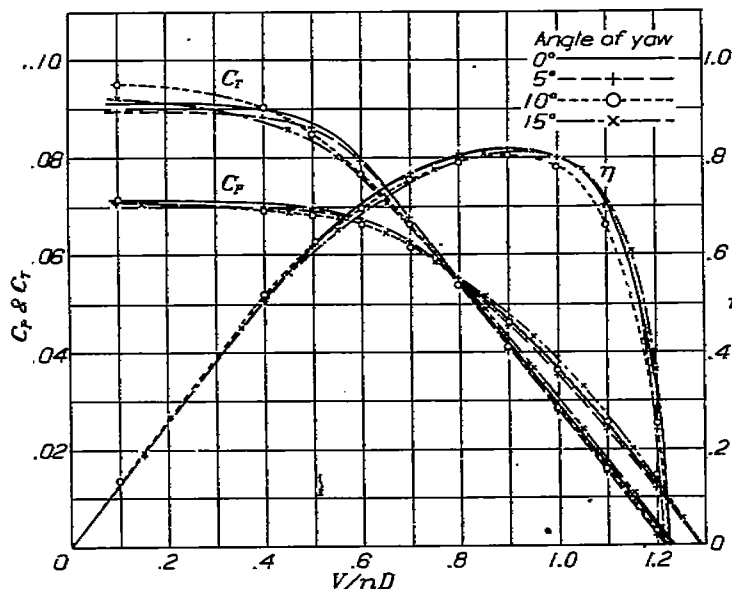


FIGURE 6.—Characteristics of propeller No. 4412, 23.5° at 0.75 R; diam. 9 ft.

+5°, +10°, and +15°) relative to the wind direction. The forces in the model tests were measured in the same manner as those in the full-scale tests, except that the torque of the motor was obtained from the calibration curve (armature current versus torque) previously determined.

For zero pitch or yaw, the resultant horizontal force on the propeller-body combination, as measured on the thrust balance, is equal to:

$$R = T - \Delta D - D$$

where T = propeller thrust (tension in propeller shaft),
 D = drag of combination without propeller (at the same dynamic pressure q),

ΔD = increment of drag due to slipstream.

The effective thrust may be defined as

$$T - \Delta D = R + D$$

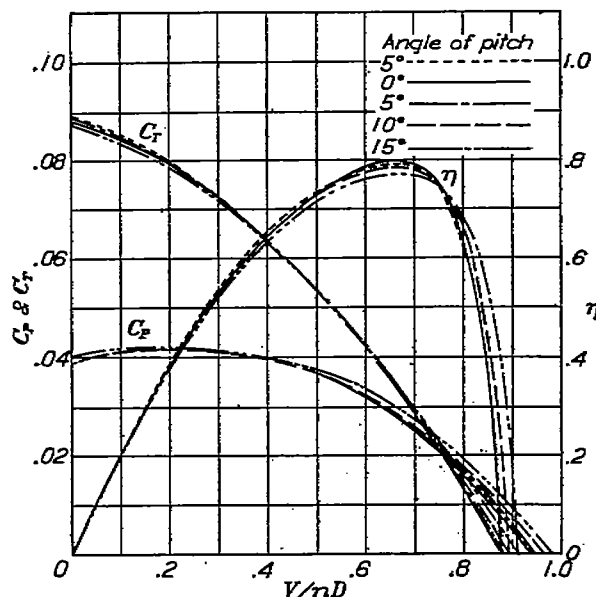


FIGURE 7.—Characteristics of propeller No. 4412; 4 ft. diam.; set 17° at 0.75 R; nacelle alone

RESULTS AND DISCUSSION

The data are reduced to the usual nondimensional coefficients of thrust, power, and propulsive efficiency:

$$\text{Thrust coefficient} = C_T = \frac{\text{effective thrust}}{\rho n^2 D^4}$$

$$\text{Power coefficient} = C_P = \frac{\text{input power}}{\rho n^3 D^5}$$

$$\text{Propulsive efficiency} = \frac{\text{effective thrust} \times \text{velocity of advance}}{\text{input power}}$$

where

ρ = mass density of the air,
 n = revolutions per unit time,
 D = diameter of propeller.

The observed data are given in Tables I and II for the full-scale tests.

The faired curves of these coefficients plotted against $\frac{V}{nD}$ are given in Figures 5 and 6. These

curves show no consistent variation with the change in the angle of yaw. The change in the thrust and power coefficients is small and the greatest variation in the peak efficiency is only 2 per cent.

The results for the model propeller tests are given in Figures 7 to 10, inclusive. Only the curves for the 17° blade settings are presented, since these are repre-

sentative of the curves for all the blade settings. The tables of these data have not been included in this report, since they are soon to be published in a report on wing-nacelle-propeller tests.

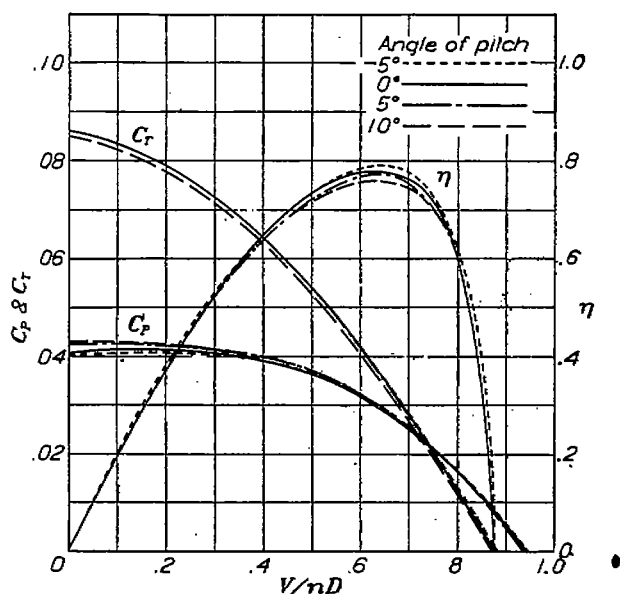


FIGURE 8.—Characteristics of propeller No. 4412; 4 ft. diam.; set 17° at 0.75 R; nacelle above wing

For the propeller with the nacelle alone (fig. 7) there is very little change in the characteristics of the propeller for the change in the angle of the thrust line. When the propeller and nacelle are placed above the

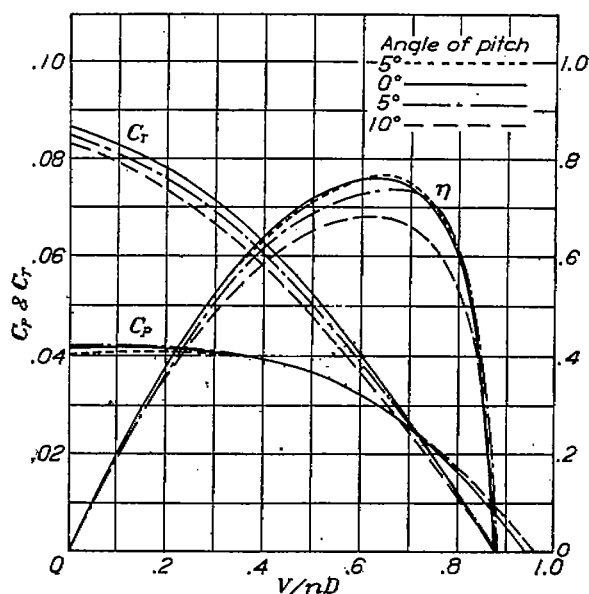


FIGURE 9.—Characteristics of propeller No. 4412; 4 ft. diam.; set 17° at 0.75 R; nacelle in front of wing

wing (fig. 8) there is a small but consistent decrease in effective thrust with increasing angle of pitch. Figures 9 and 10 show the results for the propeller and nacelle directly in front of the wing. For this condition the effective thrust decreases rapidly with increasing angle of the thrust line. For the model

engine nacelle with the propeller set at 17° (fig. 10) the decrease in effective thrust at the $\frac{V}{nD}$ of peak effi-

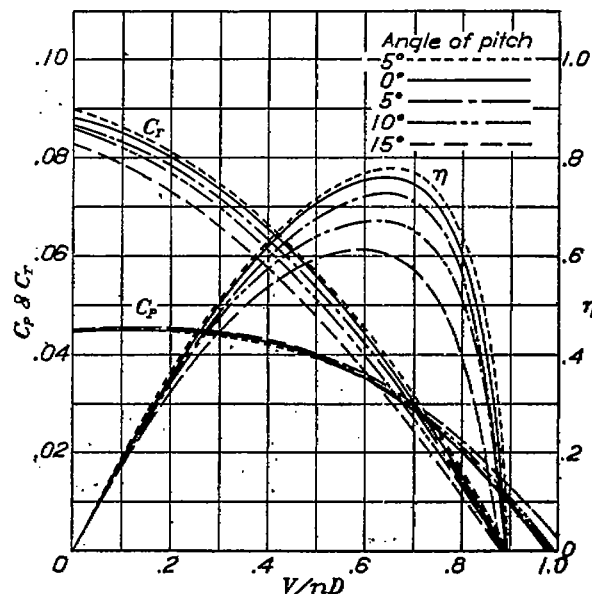


FIGURE 10.—Characteristics of propeller No. 4412; 4 ft. diam.; set 17° at 0.75 R; model engine nacelle in front of wing

ciency for a change in the angle of thrust line of 15° amounts to approximately 19 per cent.

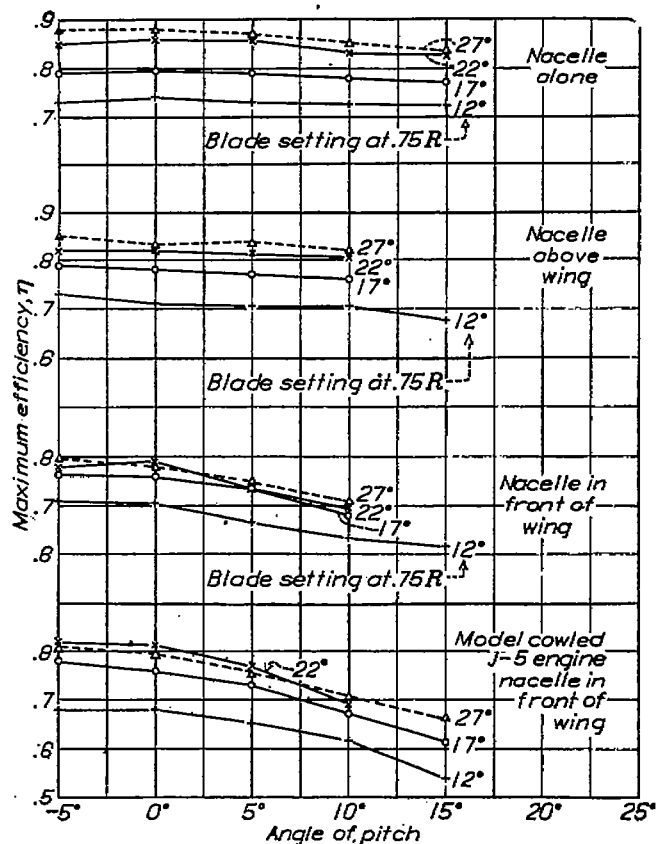


FIGURE 11.—Peak efficiencies against angles of pitch

In Figure 11 the peak efficiency, for the various blade settings and wing-nacelle combinations, has been

plotted against the angle of pitch. For the nacelle alone, the greatest change in peak efficiency for a 15° change in the angle of thrust line is 5 per cent. With the model cowled-engine nacelle, in front of the wing the greatest decrease in efficiency amounts to 15 per cent. The drop in peak efficiency is greater for the high blade settings than for the low, but the difference is small.

The results of the above tests indicate that the effect of small angles of yaw and pitch on the characteristics of a propeller is small provided there is no wing in the slipstream. However, if the propeller is working directly in front of a wing, the effective thrust and propulsive efficiency decrease rapidly with increasing angle of pitch.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY,
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
LANGLEY FIELD, VA., *January 20, 1931.*

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TABLE I
TEST RESULTS

PROPELLER 4412-23.5° AT 0.75R. 0° YAW

ρ	V m. p. h.	N r. p. m.	Q lb. ft.	T lb.	C_T	C_P	$\frac{V}{nD}$	η
0.002331	87.0	1,580	1,058	906	0.0854	0.0696	0.538	0.689
0.002331	87.0	1,580	1,058	904	0.0850	0.0696	0.538	0.689
0.002327	87.0	1,580	1,059	878	0.0815	0.0687	0.536	0.685
0.002327	92.1	1,590	1,056	884	0.0825	0.0687	0.536	0.685
0.002327	94.7	1,590	1,060	878	0.0825	0.0690	0.538	0.689
0.002327	94.7	1,590	1,058	877	0.0820	0.0687	0.538	0.689
0.002313	105.0	1,600	1,080	845	0.0782	0.0687	0.540	0.731
0.002313	105.0	1,620	1,057	840	0.0760	0.0687	0.534	0.722
0.002313	103.9	1,550	959	758	0.0749	0.0682	0.535	0.740
0.002313	103.9	1,550	957	759	0.0749	0.0682	0.535	0.740
0.002313	103.5	1,480	839	650	0.0703	0.0684	0.533	0.757
0.002313	103.5	1,480	840	649	0.0703	0.0684	0.533	0.757
0.002316	103.0	1,410	727	547	0.0651	0.0685	0.531	0.769
0.002316	103.2	1,410	728	545	0.0649	0.0685	0.531	0.769
0.002309	102.8	1,340	643	465	0.0616	0.0685	0.529	0.775
0.002309	102.9	1,350	642	464	0.0620	0.0684	0.529	0.775
0.002309	102.8	1,280	552	390	0.0567	0.0687	0.527	0.800
0.002309	102.8	1,270	554	389	0.0574	0.0687	0.527	0.800
0.002309	102.8	1,230	478	326	0.0512	0.0684	0.524	0.817
0.002309	102.8	1,220	477	324	0.0519	0.0682	0.523	0.801
0.002309	102.0	1,170	413	272	0.0473	0.0681	0.520	0.806
0.002309	102.2	1,170	412	271	0.0473	0.0681	0.520	0.806
0.002309	101.6	1,110	343	217	0.0419	0.0681	0.515	0.817
0.002309	101.8	1,100	342	215	0.0423	0.0681	0.515	0.817
0.002309	101.8	1,050	278	165	0.0356	0.0688	0.511	0.820
0.002309	101.6	1,050	278	165	0.0356	0.0688	0.511	0.820
0.002309	101.6	1,000	235	133	0.0316	0.0690	0.509	0.803
0.002309	101.6	1,010	235	132	0.0308	0.0682	0.509	0.803
0.002309	101.4	950	189	86	0.0227	0.0681	0.504	0.784
0.002309	101.2	900	126	57	0.0167	0.0685	0.501	0.712
0.002309	101.1	860	77	25	0.00805	0.0722	0.500	0.637
0.002301	101.0	800	40	1	0.00372	0.104	0.500	0.142
0.002301	101.0	780	0	-29	0.1135	0	0.500	1.267
0.002313	78.5	1,585	1,058	926	0.0878	0.0700	0.535	0.608
0.002313	78.9	1,580	1,051	922	0.0878	0.0698	0.535	0.616
0.002313	74.3	1,580	1,050	930	0.0885	0.0702	0.530	0.580
0.002313	71.1	1,580	1,053	930	0.0885	0.0700	0.531	0.557
0.002316	67.3	1,580	1,056	936	0.0891	0.0702	0.531	0.529
0.002316	67.0	1,580	1,056	937	0.0891	0.0702	0.531	0.526
0.002316	62.8	1,580	1,063	939	0.0894	0.0703	0.539	0.493
0.002316	63.0	1,580	1,060	940	0.0895	0.0704	0.539	0.496
0.002319	57.4	1,590	1,085	948	0.0899	0.0695	0.543	0.451
0.002319	56.4	1,590	1,081	940	0.0887	0.0693	0.547	0.445
0.002325	23.3	1,580	1,068	900	0.0896	0.0705	0.545	0.1838
0.002325	24.2	1,530	1,056	945	0.0853	0.0744	0.546	0.198

TABLE I—Continued
TEST RESULTS

PROPELLER 4412-23.5° AT 0.75R. 5° YAW

ρ	V m. p. h.	N r. p. m.	Q lb. ft.	T lb.	C_T	C_P	$\frac{V}{nD}$	η
0.002275	85.8	1,600	1,036	899	0.0846	0.0681	0.525	0.652
0.002275	85.8	1,600	1,036	898	0.0845	0.0681	0.525	0.652
0.002275	90.6	1,600	1,042	882	0.0830	0.0683	0.554	0.673
0.002275	90.6	1,600	1,040	882	0.0830	0.0683	0.554	0.673
0.002265	95.5	1,610	1,041	860	0.0801	0.0679	0.580	0.687
0.002265	95.5	1,610	1,041	861	0.0815	0.0679	0.585	0.694
0.002259	106.5	1,680	1,040	825	0.0764	0.0664	0.640	0.724
0.002259	106.2	1,680	1,037	821	0.0743	0.0655	0.632	0.717
0.002259	106.0	1,680	960	787	0.0735	0.0652	0.657	0.741
0.002259	103.8	1,580	859	737	0.0735	0.0650	0.657	0.744
0.002259	103.8	1,580	877	687	0.0717	0.0639	0.676	0.759
0.002259	105.0	1,480	788	685	0.0715	0.0639	0.676	0.757
0.002259	105.0	1,480	796	606	0.0675	0.0615	0.694	0.758
0.002259	104.9	1,470	791	607	0.0685	0.0621	0.704	0.772
0.002259	104.9	1,410	685	508	0.0623	0.0596	0.726	0.773
0.002259	104.9	1,400	683	508	0.0633	0.0593	0.732	0.781
0.002259	104.9	1,340	611	435	0.0596	0.0580	0.766	0.786
0.002259	104.8	1,340	611	437	0.0593	0.0580	0.763	0.780
0.002259	104.2	1,270	510	354	0.0537	0.0538	0.802	0.800
0.002259	104.0	1,260	508	353	0.0543	0.0544	0.807	0.806
0.002254	104.0	1,220	438	297	0.0486	0.0500	0.833	0.807
0.002254	103.8	1,220	439	295	0.0482	0.0501	0.831	0.800
0.002254	103.2	1,160	378	243	0.0440	0.0478	0.875	0.806
0.002246	103.4	1,170	382	249	0.0442	0.0475	0.883	0.802
0.002246	103.4	1,100	311	194	0.0391	0.0439	0.920	0.820
0.002246	103.4	1,100	311	194	0.0391	0.0439	0.920	0.820
0.002246	103.0	1,040	248	148	0.0334	0.0392	0.972	0.829
0.002246	103.0	1,040	246	144	0.0325	0.0388	0.968	0.810
0.002246	103.2	970	186	88	0.0223	0.0301	1.04	0.770
0.002246	103.2	930	131	63	0.01775	0.0258	1.053	0.746
0.002246	103.0	880	91	35	0.01101	0.0200	1.146	0.633
0.002246	103.0	820	31	-4	0.00145	0.00786	1.28	0.621
0.002256	80.3	1,630	1,033	909	0.0873	0.0694	0.544	0.619
0.002256	79.8	1,600	1,031	910	0.0865	0.0682	0.548	0.619
0.002256	74.8	1,600	1,037	919	0.0872	0.0686	0.557	0.580
0.002256	74.8	1,590	1,036	918	0.0883	0.0695	0.560	0.584
0.002259	69.4	1,600	1,010	922	0.0875	0.0687	0.544	0.540
0.002259	69.4	1,600	1,037	922	0.0875	0.0687	0.544	0.541
0.002262	65.2	1,610	1,041	927	0.0870	0.0707	0.536	0.487
0.002262	63.5	1,600	1,040	925	0.0890	0.0687	0.538	0.497
0.002262	59.0	1,600	1,045	929	0.0882	0.0689	0.561	0.462
0.002262	59.3	1,600	1,044	928	0.0881	0.0689	0.561	0.463
0.002262	56.1	1,590	1,048	931	0.0894	0.0698	0.546	0.443
0.002262	56.1	1,590	1,045	932	0.0895	0.0698	0.546	0.444
0.002267	23.8	1,590	1,051	906	0.0896	0.0703	0.546	0.181
0.002267	24.4	1,530	1,045	900	0.0908	0.0734	0.554	0.191

TABLE I—Continued
TEST RESULTS

PROPELLER 4412-23.5° AT 0.75R. 10° YAW

ρ	V m. p. h.	N r. p. m.	Q lb. ft.	T lb.	C_T	C_P	$\frac{V}{nD}$	η
0.002233	83.8	1,590	1,012	873	0.0848	0.0686	0.516	0.633
0.002233	83.8	1,590	1,010	873	0.0848	0.0686	0.516	0.633
0.002230	88.4	1,600	1,012	855	0.0821	0.0678	0.540	0.654
0.002230	88.4	1,590	1,012	858	0.0836	0.0685	0.556	0.670
0.002230	94.0	1,605	1,013	840	0.0803	0.0676	0.572	0.679
0.002230	94.6	1,620	1,011	834	0.0781	0.0662	0.571	0.674
0.002217	103.8	1,630	1,011	801	0.0746	0.0659	0.603	0.683
0.002217	102.8	1,610	1,009	801	0.0708	0.0673	0.624	0.710
0.002217	102.8	1,580	922	738	0.0747	0.0654	0.644	0.736
0.002217	102.6	1,670	923	729	0.0730	0.0647	0.638	0.719
0.002217	102.9	1,520	855	608	0.0715	0.0640	0.690	0.738
0.002217	102.8	1,510	853	606	0.0723	0.0646	0.695	0.743
0.002217	102.8	1,490	772	589	0.0684	0.0627	0.687	0.750
0.002217	102.8	1,470	778	589	0.0674	0.0616	0.683	0.747
0.002217	102.5	1,410	708	525	0.0655	0.0613	0.710	0.756
0.002217	102.5	1,410	705	526	0.0656	0.0612	0.710	0.752
0.002217	101.9	1,350	635	460	0.0624	0.0601	0.736	0.765
0.002217	101.9	1,350	632	458	0.0622	0.0599	0.736	0.765
0.002217	101.7	1,300	544	382	0.0560	0.0555	0.765	0.772
0.002217	101.7	1,290	539	381	0.0567	0.0556	0.771	0.785
0.002213	102.0	1,240	457	337	0.0544	0.0536	0.805	0.816
0.002213	101.2	1,250	457	338	0.0537	0.0528	0.797	0.810
0.002213	101.2	1,210	436	294	0.0498	0.0516	0.817	0.790
0.002213	101.0	1,180	389	256	0.0472	0.0501	0.851	0.802
0.002213	101.0	1,165	389	256	0.0468	0.0497	0.848	0.800
0.002213	100.7	1,110	330	208	0.0418	0.0462	0.885	0.802
0.002213	100.7	1,110	325	205	0.0413	0.0455	0.885	0.802
0.002213	100.7	1,070	291	179	0.0388	0.0441	0.920	0.809
0.002213	100.4	1,020	245	142	0.0358	0.0410	0.920	0.801
0.002213	100.4	1,020	247	144	0.0368	0.0409	0.904	0.797
0.002213	100.5	960	177	92	0.0343	0.0411	0.964	0.804
0.002213	100.0	890	108	48	0.0247	0.0332	1.023	0.764
0.002213	100.0	850	83	26	0.0189	0.0236	1.10	0.70
0.002213	100.0	800	46	6	0.0091	0.01981	1.15	0.617
0.002222	97.3	1,600	1,004	886	0.0856	0.0777	1.222	0.730
0.002222	78.8	1,600	1,005	870	0.0841	0.0777	0.495	0.613
0.002226	73.0	1,590	1,013	903	0.0889	0.0889	0.482	0.599
0.002226	78.0	1,590	1,009	905	0.0885	0.0889	0.480	0.660
0.002226	67.6	1,600	1,018	927	0.0892	0.0884	0.413	0.559
0.002228	66.7	1,600	1,013	927	0.0892	0.0882	0.408	0.539
0.002228	62.8	1,610	1,019	951	0.0905	0.0875	0.382	0.512
0.002228	61.9	1,610	1,017	948	0.0903	0.0875	0.378	0.503
0.002228	57.9	1,600	1,021	961	0.0925	0.0886	0.364	0.477
0.002228	57.9	1,605	1,023	957	0.0917	0.0884	0.353	0.473
0.002226	21.75	1,580	1,024	944	0.0930	0.0705	1.347	1.777
0.002228	22.26	1,540	1,017	933	0.0970	0.0736	1.412	1.890

TABLE II
TEST RESULTS

PROPELLER 4412-15.5° AT 0.75R. 0° YAW

P	V m. p. h.	N r. p. m.	Q lb. ft.	T lb.	C _T	C _P	V nD	η
0.002310	83.6	1,890	789	866	0.0576	0.0366	0.33	0.681
0.002310	84.1	1,890	789	870	0.0579	0.0366	0.35	0.688
0.002310	88.6	1,890	788	826	0.0530	0.0356	0.488	0.708
0.002310	88.0	1,900	788	826	0.0544	0.0352	0.454	0.701
0.002307	93.7	1,890	727	796	0.0505	0.0338	0.485	0.725
0.002307	93.5	1,890	731	781	0.0508	0.0340	0.484	0.723
0.002304	102.8	1,890	669	658	0.0439	0.0311	0.633	0.751
0.002304	102.8	1,890	674	662	0.0441	0.0313	0.631	0.750
0.002304	102.4	1,800	571	545	0.0401	0.0293	0.657	0.764
0.002304	101.5	1,810	573	550	0.0399	0.0290	0.649	0.755
0.002304	101.2	1,700	463	426	0.0331	0.0266	0.682	0.789
0.002304	101.2	1,700	463	425	0.0330	0.0266	0.682	0.786
0.002297	101.0	1,690	370	318	0.0300	0.0244	0.621	0.765
0.002297	101.2	1,600	372	320	0.0299	0.0242	0.620	0.766
0.002297	101.0	1,495	291	236	0.0252	0.0217	0.660	0.764
0.002297	100.3	1,420	246	173	0.0206	0.01852	0.691	0.730
0.002297	100.0	1,310	160	96	0.01333	0.01552	0.746	0.643
0.002297	99.8	1,190	83	18	0.00304	0.0076	0.820	0.266
0.002297	99.0	1,090	24	—40	0.00303	0.0337	0.896	—
0.002309	76.6	1,890	814	923	0.0513	0.0378	0.397	0.644
0.002309	76.9	1,900	816	919	0.0504	0.0375	0.397	0.638
0.002309	72.0	1,880	810	925	0.0621	0.0379	0.375	0.615
0.002309	72.0	1,880	808	925	0.0621	0.0378	0.375	0.616
0.002309	66.7	1,885	836	946	0.0632	0.0389	0.346	0.582
0.002309	66.7	1,880	837	943	0.0640	0.0392	0.347	0.586
0.002312	61.2	1,890	849	992	0.0659	0.0395	0.317	0.525
0.002312	61.2	1,890	860	994	0.0660	0.0399	0.317	0.525

TABLE II—Continued

TEST RESULTS

PROPELLER 4412-15.5° AT 0.75R. 5° YAW

P	V m. p. h.	N r. p. m.	Q lb. ft.	T lb.	C _T	C _P	V nD	η
0.002274	88.8	1,890	743	1,360	0.0537	0.0352	0.460	0.701
0.002274	88.8	1,890	744	1,360	0.0537	0.0352	0.460	0.701
0.002274	94.6	1,880	702	1,273	0.0495	0.0336	0.493	0.726
0.002274	93.0	1,880	708	1,290	0.0508	0.0338	0.494	0.720
0.002274	96.1	1,870	680	1,237	0.0478	0.0328	0.503	0.733
0.002274	95.7	1,870	685	1,245	0.0483	0.0330	0.501	0.734
0.002261	103.5	1,890	656	1,140	0.0427	0.0311	0.546	0.780
0.002261	103.5	1,900	654	1,145	0.0426	0.0307	0.543	0.784
0.002261	103.5	1,820	586	1,047	0.0392	0.0289	0.567	0.770
0.002261	103.5	1,820	585	1,044	0.0390	0.0289	0.567	0.766
0.002261	103.8	1,705	447	903	0.0326	0.0260	0.604	0.788
0.002261	104.0	1,705	448	928	0.0343	0.0261	0.596	0.784
0.002280	76.0	1,870	797	1,605	0.0623	0.0394	0.395	0.646
0.002280	73.0	1,880	799	1,504	0.0615	0.0380	0.390	0.631
0.002280	82.0	1,900	795	1,459	0.0656	0.0370	0.422	0.670
0.002280	82.0	1,890	793	1,461	0.0593	0.0372	0.424	0.676
0.002261	105.7	1,620	364	628	0.0293	0.0235	0.637	0.795
0.002261	105.0	1,610	368	713	0.0214	0.01995	0.690	0.780
0.002261	104.8	1,400	188	633	0.01485	0.01626	0.732	0.660
0.002261	104.8	1,300	123	564	0.00705	0.01280	0.787	0.451
0.002266	104.5	1,190	45	502	0.00258	0.00575	0.869	—
0.002263	70.3	1,880	798	1,536	0.0623	0.0381	0.366	0.607
0.002268	70.3	1,870	801	1,535	0.0633	0.0386	0.368	0.608
0.002271	65.1	1,870	807	1,661	0.0645	0.0395	0.341	0.570
0.002271	64.8	1,870	817	1,563	0.0649	0.0394	0.339	0.558
0.002271	60.7	1,880	812	1,686	0.0652	0.0385	0.316	0.531
0.002271	60.7	1,870	813	1,687	0.0660	0.0391	0.317	0.535

TABLE II—Continued
TEST RESULTS

PROPELLER 4412-15.5° AT 0.75R. 10° YAW

P	V m. p. h.	N r. p. m.	Q lb. ft.	T lb.	C _T	C _P	V nD	η
0.002288	87.4	1,890	771	820	0.0551	0.0362	0.452	0.688
0.002288	86.7	1,890	771	822	0.0552	0.0362	0.445	0.684
0.002285	91.5	1,890	730	757	0.0509	0.0342	0.473	0.706
0.002285	91.5	1,890	731	761	0.0511	0.0344	0.473	0.704
0.002277	95.6	1,880	700	711	0.0436	0.0333	0.498	0.726
0.002277	95.6	1,880	700	712	0.0457	0.0333	0.498	0.728
0.002271	105.0	1,900	626	630	0.0422	0.0307	0.540	0.743
0.002271	104.9	1,900	636	639	0.0427	0.0307	0.540	0.751
0.002271	104.8	1,800	550	513	0.0383	0.0256	0.570	0.763
0.002271	104.8	1,810	560	508	0.0374	0.0254	0.567	0.746
0.002271	103.5	1,635	444	394	0.0332	0.0261	0.597	0.789
0.002271	103.5	1,690	442	395	0.0334	0.0261	0.599	0.785
0.002264	103.8	1,590	351	293	0.0250	0.0224	0.639	0.764
0.002264	103.8	1,590	352	293	0.0250	0.0225	0.639	0.762
0.002267	103.4	1,470	256	191	0.0214	0.0200	0.639	0.786
0.002267	102.8	1,400	201	139	0.01780	0.01736	0.715	0.709
0.002267	102.0	1,360	135	72	0.01032	0.01500	0.770	0.589
0.002267	102.0	1,220	84	19	0.00309	0.00552	0.817	0.285
0.002267	102.0	1,120	22	—35	0.00374	0.00509	0.890	—
0.002276	78.2	1,890	789	881	0.0595	0.0372	0.404	0.645
0.002276	78.0	1,890	787	881	0.0594	0.0370	0.403	0.646
0.002279	78.7	1,890	810	899	0.0627	0.0382	0.381	0.625
0.002279	72.0	1,890	810	895	0.0632	0.0382	0.378	0.626
0.002279	67.4	1,890	857	984	0.0665	0.0389	0.343	0.585
0.002279	67.4	1,890	850	946	0.0673	0.0390	0.343	0.600
0.002282	61.7	1,870	835	1,020	0.0700	0.0401	0.323	0.564
0.002282	62.1	1,880	832	1,023	0.0696	0.0395	0.324	0.571

TABLE II—Continued

TEST RESULTS

PROPELLER 4412-15.5° AT 0.75R. 15° YAW

P	V m. p. h.	N r. p. m.	Q lb. ft.	T lb.	C _T	C _P	V nD	η
0.00231	89.0	1,900	773	804	0.0540	0.0363	0.458	0.682
0.00231	89.0	1,900	773	806	0.0542	0.0363	0.458	0.684
0.00231	92.6	1,890	728	747	0.0507	0.0346	0.479	0.708
0.00231	92.4	1,890	727	748	0.0508	0.0345	0.478	0.705
0.002307	95.5	1,890	692	698	0.0477	0.0330	0.494	0.714
0.002307	94.2	1,880	692	709	0.0490	0.0334	0.490	0.719
0.002304	103.9	1,890	653	625	0.0428	0.0312	0.567	0.737
0.002304	103.7	1,890	659	632	0.0432	0.0314	0.536	0.737
0.002304	103.6	1,810	560	534	0.0395	0.0291	0.560	0.766
0.002304	103.3	1,810	560	532	0.0396	0.0291	0.558	0.760
0.002304	102.9	1,690	442	395	0.0337	0.0264	0.596	0.761
0.002304	103.0	1,690	442	395	0.0337	0.0264	0.596	0.761
0.002297	103.0	1,600	364	311	0.0298	0.0244	0.630	0.770
0.002297	103.0	1,600	367	312	0.0299	0.0245	0.630	0.765
0.002297	102.6	1,500	292	235	0.0256	0.0225	0.669	0.769
0.002297	102.1	1,410	232	173	0.0213	0.0200	0.708	0.755
0.002297	101.9	1,300	150	91	0.0132	0.0152	0.766	0.665
0.002297	101.6	1,210	94	37	0.0082	0.0110	0.821	0.462
0.002297	101.3	1,100	27	—26	0.00507	0.00881	0.901	—
0.002309	81.2	1,890	778	843	0.0575	0.0371	0.420	0.650
0.002309	81.4	1,890	776	836	0.0571	0.0370	0.421	0.650
0.002309	75.9	1,890	808	899	0.0617	0.0385	0.393	0.627
0.002309	75.8	1,890	809	893	0.0610	0.0385	0.392	0.620
0.002309	71.4	1,890	820	926	0.0633	0.0391	0.369	0.597
0.002309	71.1	1,900	824	929	0.0635	0.0389	0.366	0.597
0.002312	63.8	1,880	826	973	0.0672	0.0398	0.332	0.560
0.002312	63.9	1,890	826	976	0.0666	0.0391	0.331	0.565
0.002312	59.5	1,880	831	999	0.0690	0.0400	0.310	0.535
0.002312	59.6	1,880	831	1,001	0.0691	0.0400	0.310	0.536
0.002312	58.3	1,850	833	1,011	0.0699	0.0401	0.303	0.529
0.002312	55.8	1,880	836	1,022	0.0706	0.0402	0.290	0.510
0.002312	17.80	1,880	871	1,164	0.0798	0.0418	0.0236	0.177
0.002312	18.36	1,890	871	1,167	0.0800	0.0415	0.0250	0.183